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Original Article

TEMPORAL AND SPATIAL PATTERNS OF HONEYBEE COLONY WINTER LOSSES IN POLAND FROM AUTUMN 2006 TO SPRING 2012; SURVEY BASED ON SELF-SELECTED SAMPLES

Grażyna Topolska*
Anna Gajda
Urszula Imińska

Warsaw University of Life Sciences, Faculty of Veterinary Medicine, Department of Pathology and Veterinary Diagnostics, Laboratory of Bee Diseases, Poland

*corresponding author: grazyna_topolska@sggw.pl
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Summary

Estimations of honeybee colony winter losses in Poland have been carried out at Warsaw University of Life Sciences since 2008 (in 2008 they concerned the two winters of 2006/07 and 2007/08), using a preliminary questionnaire in 2008 and the standardized COLOSS questionnaire since 2009. During the first years of the survey, concerning the period of autumn 2006 - spring 2012, the multimode method of data collection was used, and beekeepers sent in between 393 and 769 questionnaires a year. Overall, the number of participants increased, but in particular voivodeships it fluctuated. The estimated overall winter colony loss in Poland was low during the winter of 2006/07 (10%) and quite low during the winter of 2008/09 (11.5%). In other years it was substantially higher reaching 15.2% in 2007/08, 14.8% 2009/10, as much as 18.3% in 2010/11 and then down to 15.8% in 2011/12. A similar pattern of average losses was observed, but each year, excluding the winter of 2010/11, at least 50% of beekeepers reported acceptable losses of only up to 10%. During the analysis of the spatial pattern of overall losses, some data which could blur the pattern were eliminated. The results suggest that such climatic factors as a warm autumn but also high summer precipitation, followed by low winter temperatures influenced the spatial distribution of the losses.

Keywords: *Apis mellifera*, climatic factors, colony winter losses, Poland, survey

INTRODUCTION

The most recent enormous honey bee (*Apis mellifera*) colony winter losses were documented for the first time in 2007 when 31.8% of colonies in the USA turned out to have been lost during winter (vanEngelsdorp et al., 2007). A year later increased losses appeared in many European countries (Hendrix et al., 2009). Since then, winter colony losses have been a serious problem in both regions and every year scientists investigate the magnitude of this phenomenon. In Europe the survey is performed by a group of honey bee experts active within the network called COLOSS (Prevention of honey bee COlony LOSSes) designated in June 2008 by the European Union as the COST Action. In 2009 the standardized COLOSS questionnaire was introduced to assess colony losses and is evaluated and improved each year to allow for a better calculation of losses and assessment of risk factors.

Some analyses of the international results concerning losses during the winters of 2008/09, 2009/10 and 2012/13 were published by van der Zee et al. in 2012 and 2014. The data showed that the losses varied from region to region. The Coloss Press Releases in 2013, 2014, 2015 and 2016 on colony losses showed that the losses in particular regions varied also from year to year. Researchers at Warsaw University of Life Sciences have been participating in the estimation of colony losses by performing the survey in Poland, using a preliminary questionnaire in 2008 and the standardized COLOSS questionnaire since 2009. During the first years of the survey multimode methods of data collection were used, but since 2013, stratified

randomized sampling has been applied for the selection of beekeepers to whom the questionnaire was sent. Some data collected during surveys were used in papers by Topolska, Gajda & Hartwig (2008) and Topolska et al. (2010).
The aim of this work is to analyze the temporal and spatial pattern of winter honeybee colony losses in Poland in the period from autumn 2006 to spring 2012, investigated using the multimode method of data collection based mainly on a self-selected sample. The full set of collected relevant data was analyzed, including the information from questionnaires which had been sent in late and could not be used in the analyses in previous publications. A new approach to the analysis of data was also introduced.

MATERIAL AND METHODS

Questionnaire

The survey was based on a self-administered questionnaire. The preliminary questionnaire, used in 2008 in Poland, contained only a few questions about the number of colonies wintered in 2006, the number of colonies which survived the winter and relevant questions concerning the following winter. The questionnaire also asked for the address of the beekeeper, although anonymous participation was possible too. The COLOSS questionnaire (used since 2009), standardized at the European level and elsewhere, contained questions that allowed the estimation of winter colony losses and possible risk factors. Every year there was a question concerning the number of colonies wintered by the beekeeper (or colonies owned on the 1st of October - 2010 questionnaire). The number of colonies lost by the beekeeper was usually directly provided by the beekeeper himself, but in the 2010 survey it was calculated from the number of colonies owned on the 1st of October and next on the 1st of April. Each year beekeepers were also asked to provide their address and, since 2011, also the postal code of the apiary or name of a nearby city. The English version of the COLOSS questionnaire used in 2012 was published in a multi-author international paper (van der Zee et al., 2013). The questionnaire referred to production colonies. Case definitions used in the COLOSS questionnaire were as follows: production colony - colony queen-right and strong enough to provide honey harvest; lost colony – dead colony or colony reduced to a few hundred bees, or alive but with queen problems like drone laying queens or no queen at all, which could not be solved; winter - the period between the moment of finishing the pre-winter preparations and the start of the new foraging season.

The methods of data collection

In 2008 the preliminary questionnaire concerning the winters 2006/07 and 2007/08 was distributed among beekeepers and collected during various meetings and conferences with the active participation of beekeeping associations. In the following years, the methods of data collection were extended, and even an Internet survey was implemented on www.beemonitoring.org (courtesy of Romee van der Zee). In 2012, the questionnaire was published in "Pszczelarstwo" and "Pszczelarz Polski", the two most popular Polish beekeeping journals with a joint circulation of 18,500, and disseminated at beekeeping meetings and conferences, with an Internet version also available. In addition, invitation letters and reminders were emailed to the beekeepers who had participated in the survey in previous years and had their addresses stored in the Beemonitoring database. Finally, the questionnaire form was posted to randomly selected beekeepers from the Polish Veterinary Inspection list of the five regions where participation was very low (free return postage was offered). Each year a deadline for returning the questionnaire was set.

Methods of data analysis including statistics

All the colonies owned by one beekeeper (operation) were treated as one apiary.
The data were cleared by excluding repetitions, apiaries with no colonies during wintering and operations with more colonies lost than going into winter.
Overall loss rates (overall proportion of colonies lost) for each year, with ninety-five percent confidence intervals (95% CI), was estimated

using an intercept-only quasi-binomial generalised linear model (GLM) with logit link (The R Foundation for Statistical Computing, 2016) following the standard procedure outlined by van der Zee et al., (2013). The estimated overall loss rate was the total number of colonies lost as a proportion of total number of colonies at risk (going into the relevant winter).

The average loss for each year was calculated by adding the loss experienced by each beekeeper in a given year, then dividing that sum by the number of responding beekeepers in that year. For a descriptive analysis of the spatial pattern of colony losses, the losses were divided into four categories: acceptable losses – up to 10%, moderate losses – over 10% and up to 15%, high losses –over 15% and up to 20%, very high losses – over 20%.

Operations with "outliers", that is an unusually high number of colonies in a given voivodeship, were not included during the creation of maps showing overall losses by voivodeship. The "outliers" were calculated using Statistica 13.1 (StatSoft). Only the voivodeships from which at least ten questionnaires were received were included.

Maps with location of apiaries with losses falling into the categories of low- acceptable, moderate and higher than moderate were created with www.easymapmaker.com. Only data from beekeepers with at least ten colonies were used, since in smaller apiaries/operations the losses are always higher than 10% (unless there are no losses at all). The apiaries from voivodeships with low beekeeper response (below 10 questionnaires) were included. The maps concerning the winters of 2010/11 and 20011/12, when a higher number of beekeepers took part in the survey, were compared with the climatic maps of Poland regarding average monthly temperatures and precipitation taken from the IMGW-PIB webpage (http://old.imgw.pl/klimat/.)

RESULTS

Number of respondents

In total we received between 348 and 769 questionnaires a year (Tab. 1). About 10% of questionnaires arrived after the deadline. In the survey conducted in 2008, concerning the winters of 2006/07 and 2008/09, the number of respondents was higher than nine in only seven voivodeships, but each following year the situation improved, even though in particular voivodeships the number fluctuated. In regions where questionnaires in a particular year were handed out at meetings and conferences or beekeeping associations were actively involved in disseminating and collecting the questionnaires, the number of respondents was much higher than in the others. The number of operations with an unusually high number of colonies - "outliers", varied from 0 to 15 depending on the year (Tab. 2).

Winter colony losses

The estimated overall winter colony loss in Poland was low (10%, 95% confidence interval 8.7-11.5%) during the winter of 2006/07 and quite low during the winter of 2008/2009 (11.5%, 95% CI 9.7 - 13.5%). The highest value occurred during the winter of 2010/11 reaching 18.3% (95% CI 16.8 - 19.9%). In the other years losses were as follows: 2007/08 - 15.2% (95% CI 13.6 - 17.4%), 2009/10 - 14.8% (95% CI 12.9 - 16.7%), 2011/12 - 15.8% (95% CI 13.6 - 17.4%). A similar pattern was observed in case of average losses: 2006/07 - 12.3%, 2007/08 - 15.4%, 2008/09 - 13.2%, 2009/10 - 17.0%, 2010/11 - 22.6%, 2011/12 - 17,3%, but each year, besides the winter of 2010/11, at least 50% of beekeepers reported acceptable levels of losses (up to 10%) (Fig. 1).

Overall losses in particular voivodeships varied from year to year (Tab. 3). The highest losses reached 31% in the Lower Silesian voivodeship during the winter of 2010/11. However during the winter of 2011/12, losses were higher than acceptable in all voivodeships. Because the beekeepers with "outliers", that is an unusually high number of colonies in a given voivodeship, were excluded, the losses fell into a higher category in three voivodeships in the survey concerning the winters of 2006/07, 2 - 2007/08, 3 - 2008/09, 3 - 2009/10, 5 - 2010/11 and 5 - 2011/12, but into a lower category in one voivodeship in the survey concerning the

Table 1.

Number of all operations (questionnaires) with valid data for honey bee colony losses (Qst) and mean number of colonies owned by respondents in autumn (Col), by voivodeship and in each winter (between autumn 2006 – spring 2012) in Poland

Voivodeship	Winter											
	2006/07		2007/08		2008/09		2009/10		2010/11		2011/12	
	Qst	Col	Qst	Col	Qst	Col	Qst	Col	Qst	Col	Qst	Col
Greater Poland	46	50	49	43	75	56	150	41	24	40	41	38
Kuyavian-Pom	54	56	56	55	7	-	5	-	65	38	17	57
Lesser Poland	1	-	1	-	66	41	51	50	186	26	60	69
Lodz	5	-	5	-	0	-	5	-	30	23	46	25
Lower Silesian	64	25	84	27	13	24	20	33	58	44	50	38
Lublin	36	58	38	56	57	37	7	-	20	37	42	33
Lubusz	3	-	3	-	2	-	22	29	6	-	18	37
Masovian	2	-	2	-	45	42	35	41	52	27	34	33
Opole	1	-	1	-	9	-	4	-	75	25	35	32
Podlachian	4	-	4	-	0	-	7	-	12	22	10	39
Pomeranian	55	44	55	39	5	-	1	-	32	28	9	-
Silesian	0	-	0	-	16	52	19	30	165	21	116	16
Subcarpathian	1	-	1	-	31	47	44	53	12	67	29	38
Swietokrzyskie	2	-	2	-	14	49	1	-	7	-	26	26
Warmian-Mazurian	56	105	57	117	5	-	3	-	4	-	45	49
Western Pomeranian	63	0	62	53	3	-	38	45	20	34	36	2
Unspecified	0	-	0	-	0	-	0	-	1	-	5	-
Total	393	-	420	-	348	-	412	-	769	-	619	-

(-) - data not included because number of received questionnaires was lower than 10

winters of 2006/07, 3 - 2007/08, 1 - 2008/09, 1 - 2010/11 and two in the survey concerning the winter of 2011/12. For example, in the Lublin voivodeship, where one of the 38 participating beekeepers in 2007 wintered an enormous number of colonies and lost most of them, the exclusion of this operation from the analysis (together with two other big operations but with moderate losses) lowered the average loss in voivodeships from 26.1% to 11.6%. Whereas, the elimination of the two with "outliers" from the 45 participating apiaries in the Warmian-Mazurian voidvodeship in 2012 resulted in a rise in the calculated overall loss in this voivodeship from 16.5% to 21.4%.

An analysis of the data from the operations without "outliers", showed that in the winter of 2007/08 the losses in three out of seven voivodships were higher than during the previous winter (Fig. 2). However, already during the winter of 2006/07, losses were already high in two voivodeships, Greater Poland and West Pomeranian, while overall losses were acceptable in the rest of the country. Generally, a tendency has been observed over the years towards a decrease in

Table 2.

Number of operations (questionnaires) with "outliers"*, with valid data for honey bee colony losses (Qst) and mean number of colonies owned by these operations in autumn (Col), by voivodeship and in each winter (between autumn 2006 – spring 2012) in Poland

Voivodeship	Winter											
	2006/07		2007/08		2008/09		2009/10		2010/11		2011/12	
	Qst	Col	Qst	Col	Qst	Col	Qst	Col	Qst	Col	Qst	Col
Greater Poland	0	0	7	178	4	213	8	182	1	200	0	0
Kuyavian-Pom	3	312	4	260		-	5	-	1	115	1	140
Lesser Poland	-	-	-	-	5	205	5	204	15	133	5	153
Lodz	-	-	-	-	0	0	-	-	3	73	4	66
Lower Silesian	6	92	5	102	1	100	1	208	3	153	4	164
Lublin	4	230	3	317	7	124	-	-	0	0	1	200
Lubusz	-	-	-	-	-	-	-	-	6	-	0	0
Masovian	-	-	-	-	4	132	1	153	5	109	5	105
Opole	-	-	-	-		-	-	-	3	79	0	0
Podlachian	-	-	-	-	-	-	-	-	1	75	0	0
Pomeranian	4	204	0	0	-	-	-	-	3	78	-	-
Silesian	-	-	0	-	2	245	1	105	14	66	7	70
Subcarpathian	-	-	-	-	2	263	2	353	1	480	1	120
Swietokrzyskie	5	704	-	-	0	0	-	-	-	-	1	90
Warmian-Mazurian	0	0	7	615	-	-	-	-	-	-	2	390
Western Pomeranian	0	0	2	520	3	-	2	152	1	150	2	210
Unspecified	-	-	-	-	-	-	-	-	-	-	5	-
Total	22		28		28		25		57		37	22

* "outliers" - unusually high number of owned colonies

(-) - data not included because number of received questionnaires was lower than 10

the proportion of voivodeships with acceptable losses. The spatial pattern showed that neighboring voivodships often had losses of similar size.

The spatial pattern of losses experienced by beekeepers with more than ten colonies shows some areas in which apiaries with high and very high losses (losses above 15 %) made up about 50% of those investigated in the winters of 2010/11 and 2011/12. (Fig. 3). During the first winter, these were in south western Poland, where the mean temperatures in October 2010 were above 6°C (Fig 4.), and during the second winter, the problem of high and very high winter losses concerned mainly the eastern half of Poland, where not only total precipitation in the preceding July was very high (exceeding 220 mm) (Fig. 5), but also the mean temperature in December was low (below 3°C) (Fig. 4). During the same July the mean temperature was high reaching at least 18°C (Fig. 4).

Table 3.

Overall honey bee colony winter losses (%), in voivodeships with at least ten respondents, experienced by all the operations (All) and the operations without "outliers" (E) in Poland between autumn 2006 - spring 2012

Voivodeship	Winter											
	2006/2007		2007/2008		2008/2009		2009/2010		2010/2011		2011/2012	
	All	E	All	E	All	E	All	E	All	E	All	E
Greater Poland	14.8	↑ 16.6	24.6	26.7	9.3	↑ 11.0	14.5	14.8	12.4	↓ 9.3	17.4	17.4
Kuyavian-Pomeranian	10.4	↑ 11.1	12.2	↓ 10.5					15.8	16.1	10.0	↑ 11.1
Lesser Poland							13.7	↑ 16.6	14.4	↑ 18.3	18.5	16.6
Lodz					6.2	8.6			18.4	17.2	22.0	↓ 18.6
Lower Silesian	11.1	11.3	11.2	↓ 9.9	7.2	↑ 10.6	13.8	14.2	31.0	32.0	9.9	↑ 12.8
Lublin	8.1	↑ 11.4	26.1	↓ 11.6	11.5	13.3			12.3	12.3	21.8	↓ 17.8
Lubusz							19.1	19.1			14.4	14.4
Masovian					6.5	6.9	18.0	19.7	17.8	19.4	18.0	↑ 21.2
Opole									18.7	↑ 20.7	11.5	11.5
Podlachian									10.7	15.0	14.8	12.2
Pomeranian	10.8	↓ 9.2	8.4	9.9					8.7	↑ 11.0		
Silesian					13.3	↓ 9.2	19.7	↑ 22.2	25.4	30.0	11.5	11.1
Subcarpathian					12.8	↑ 17.4	15.3	↑ 17.0	8.8	↑ 12.6	21.6	21.6
Swietokrzyskie					13.9	13.9					16.3	17.9
Warmian-Mazurian	10.0	9.4	9.5	↑ 14.8							16.5	↑ 21.4
West Pomeranian	18.5	20.2	24.8	↑ 27.3			6.9	7.5	17.4	↑ 21.7	13.6	↑ 16.8

"outliers" - unusually high number of owned colonies in voivodeship
"↑"- category of losses increased after elimination of operations with "outliers",
"↓"- category of losses lowered after elimination of operations with "outliers",

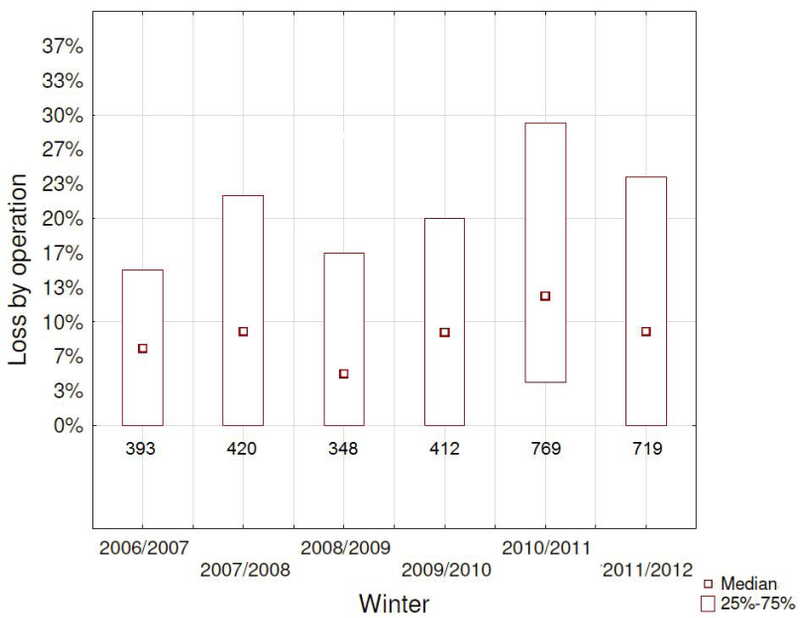

Fig. 1 Box plot of dispersion of honey bee colony winter losses among beekeepers in Poland between autumn 2005 – spring 2012; N- number of operations (respondents)(Statistica v.13.1, 2015).

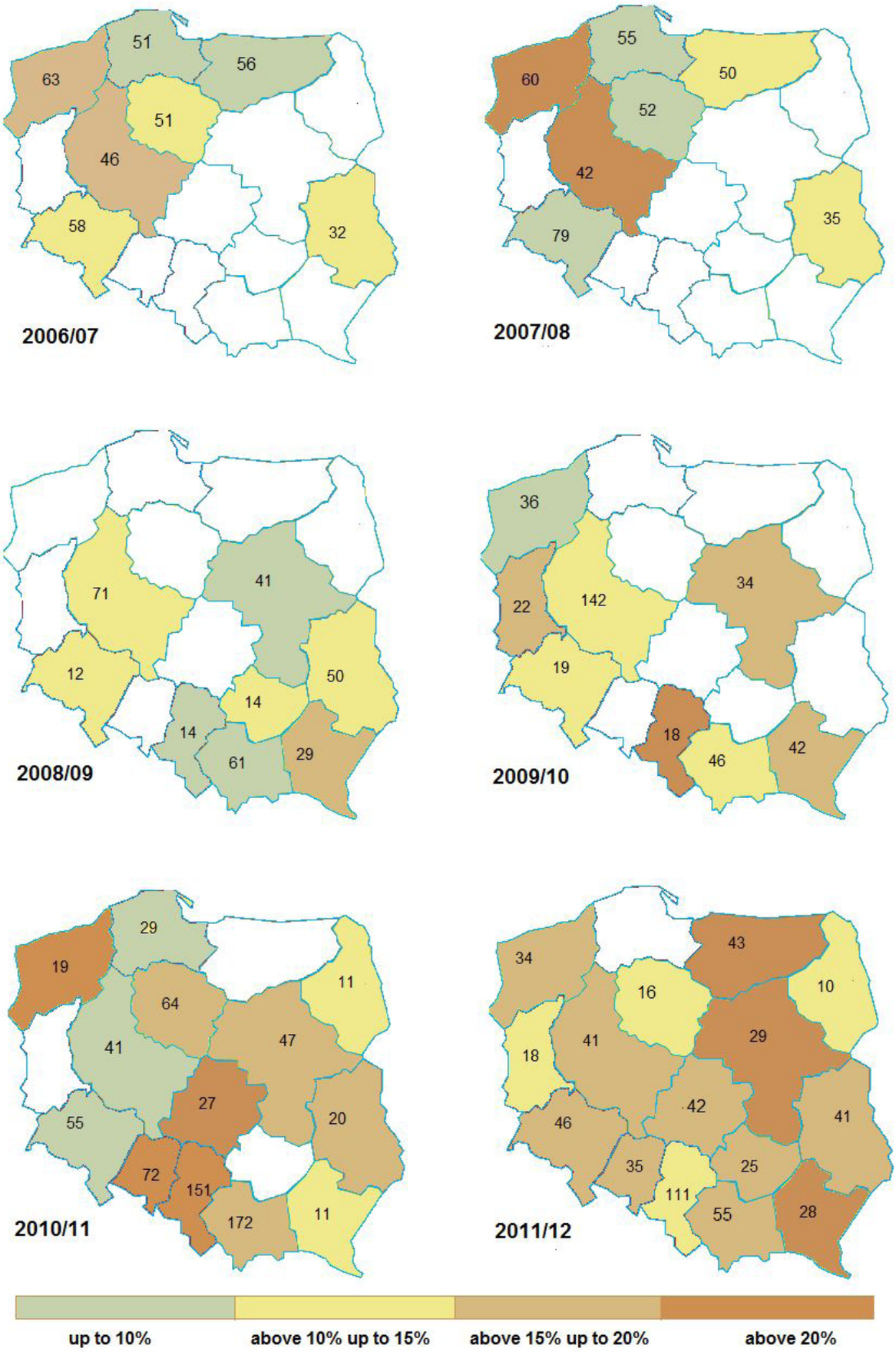

Fig. 2 Modified spatial pattern of overall honey bee colony losses in Poland between autumn 2006 – spring 2012; N= number of operations (operations with an usually high number of colonies in voivodeship were excluded).

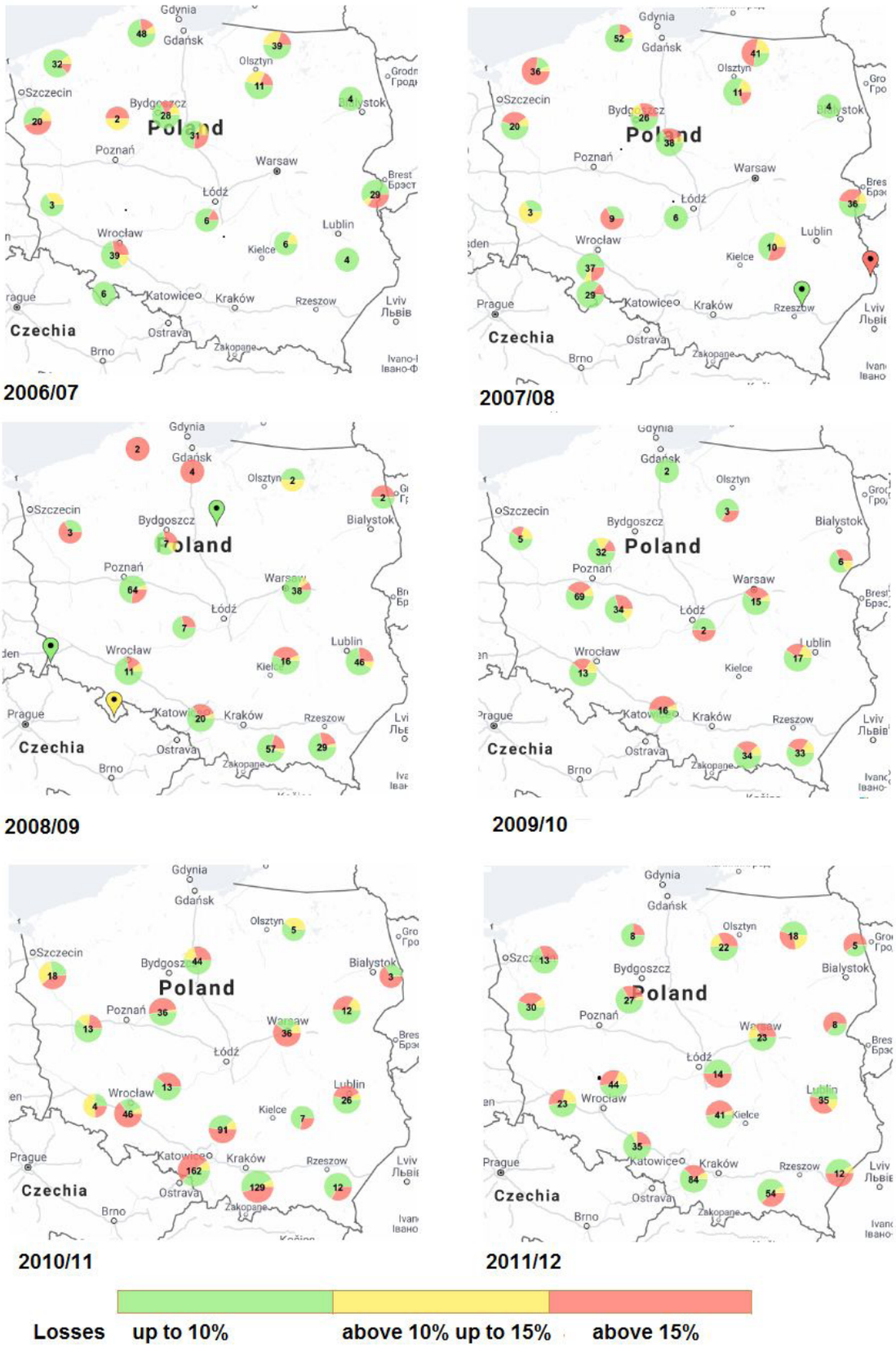

Fig. 3 Maps with location of operations with honey bee colony winter losses of different size experienced in Poland between autumn 2006 – spring 2012 (operations with less than 10 colonies were excluded). Circle graphs show the proportion of operations with losses of different size in a particular area; N= number of operations covered by the graph.

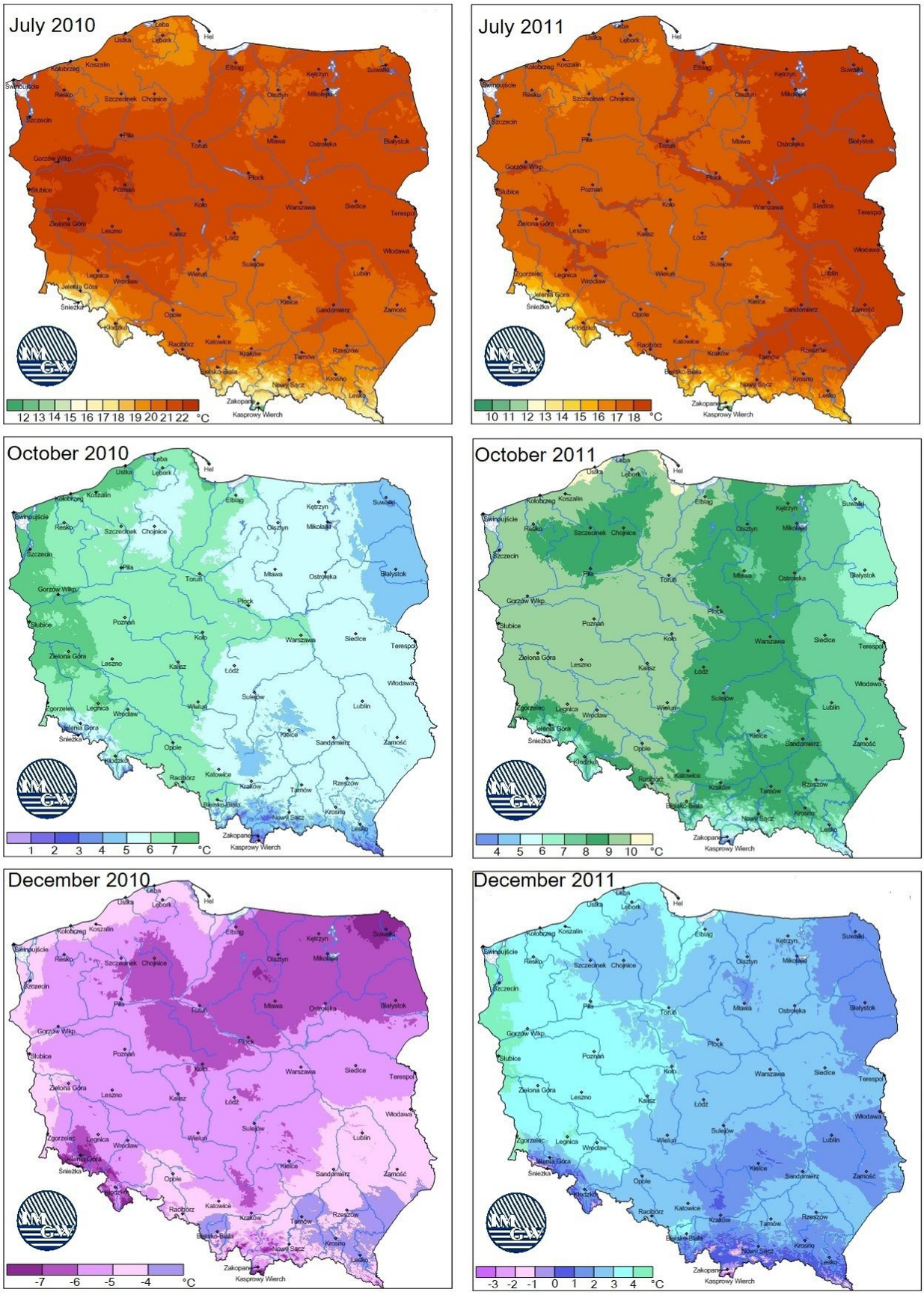

Fig. 4 Climatic maps of Poland showing mean temperatures in July, October and December of 2010 and 2011. Adapted with permission from "Mapy klimatyczne Polski" by Instytut Meteorologii i Gospodarki Wodnej.

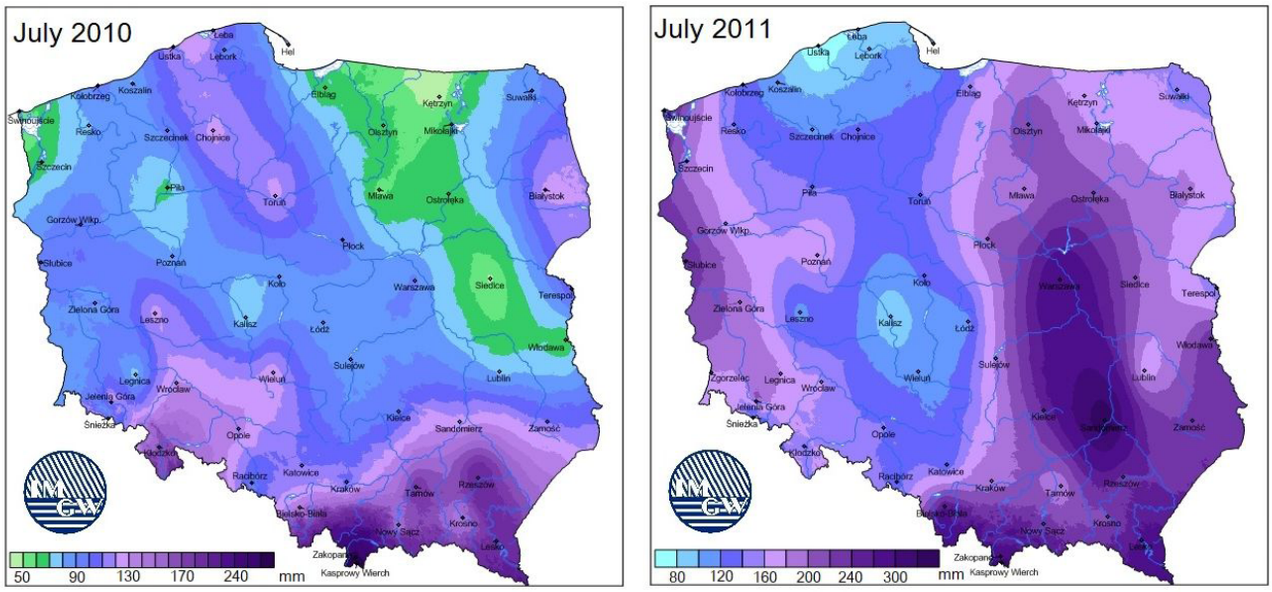

Fig. 5 Climatic maps of Poland showing precipitation totals in July 2010 and July 2011. Adapted with permission from "Mapy klimatyczne Polski" by Instytut Meteorologii i Gospodarki Wodnej.

DISCUSSION

Poland, a relatively big country covering an area of 312,679 square kilometers, has a large number of beekeepers. According to an analysis of the beekeeping sector (Semkiw, 2013), between 2006 and 2012 there were between 40 000 and 45 000 beekeepers in Poland belonging to 30 beekeeping associations. Collecting the data on colony losses was not easy even when all possible methods of data collection were used. Beekeepers were at first rather reluctant to participate in some regions, unless the problem of losses became serious or the surveyor participated in a beekeeping conference in the region. Internet surveys were not particularly useful as beekeepers seldom use the Internet. However, the pattern of beekeepers' participation in different voivodeships changed from year to year. In the survey performed in 2012, posting the questionnaire to randomly selected individual beekeepers from voivodeships in which participation of beekeepers was very low equalled the number of participants from different voivodeships in the study quite efficiently.

Beekeepers in Poland tend to accept the loss of 10% of colonies during the winter as in most European countries. However, in the last ten years many of them have suffered higher losses and this has influenced the overall losses in the country which in this study are shown to have been unacceptably high since the winter of 2007/08. In many European countries the situation has changed from year to year, but there were also such places as the Netherlands where the losses were usually high (van der Zee et al., 2015). In Poland in the period from autumn 2006 to spring 2012 the situation improved only during the winter of 2008/09. However, each year, beside the winter of 2010/11 when the losses were the highest, 50% of beekeepers experienced acceptable losses (up to 10 %), which suggests that many beekeepers managed to save their bees. In the US and in many European countries, this usually concerned big operations (van der Zee et al., 2014; Lee et al., 2015; Brodschneider et al., 2016).

Spatial distribution of the overall losses throughout the country is very important from the point of view of pollination services and is also a subject of interest to beekeepers. However, these losses are very sensitive to the size of losses in big apiaries, even if these are few. Thus, excluding from the analysis apiaries with "outliers" can be helpful in the analysis of the possible influence of geographical position on the level of losses. The maps of overall losses

in voivodeships created after such an elimination revealed that, although during the first investigated winter (2006/07) the overall losses in the country were at an acceptable level, in two voivodeships (West-Pomeranian and Greater Poland) the losses were substantially higher (above 10 % and up to 15%). These regions experienced high losses the following year.

These maps also show that substantially increased losses often concerned two or more neighboring voivodeships, which suggests the possible influence of some factors associated with the location, primarily climate. According to Austrian researchers (Switanek et al., 2017), there is a lack of studies on the influence of climatic factors on honeybee colony losses. Therefore, on the basis of data collected from 2009-2014, they built a statistical model to predict colony mortality using temperature and precipitation data and found that warmer and drier weather conditions in the preceding year were accompanied by increased winter mortality. However, in the survey performed in the US in 2008 the authors found that regions with relatively lower average temperatures had higher winter colony losses (vanEngelsdorp et al., 2008). This can also be concluded on the basis of maps with distribution of average winter losses in the US during the winter of 2016/17 (Kulhanek et al., 2017).

To investigate the issue, we created maps of apiaries' locations with acceptable (up to 10 %), moderate (above 10 % and up to 15%) and higher than moderate (above 15%) losses. Because small apiaries with fewer than ten colonies were excluded from the analysis, a loss could have occurred in every category. In excluded, small, apiaries a loss of even one colony means a loss of over 10%, so is higher than acceptable, and the loss of two colonies, which often occurs for various reasons, means a loss of over 20% and already falls into the category of very high losses. The comparison of these maps of losses in the last two years of the investigation, when the beekeepers participated more equally, with climatic maps of Poland revealed that the area in which almost 50% of apiaries suffered high or very high losses during the winter corresponds with the area where winter was short because of a warmer October (concerns the winter of 2010/11).

"Short winter" means a long period in which the brood is present in the colony, thus facilitating growth of the *Varroa destructor* population together with associated virus infections. These pathogens are considered one of the main causes of honey bee colony losses during winter time (Kielmanowicz et al., 2015), which was also confirmed by the results of the investigation of bee samples collected in Poland from colonies which died during winter or originated from apiaries with high honey bee colony winter losses (Topolska, Gajda & Hartwig, 2008; Topolska et al., 2010; Pohorecka et al., 2011; Pohorecka et al., 2014).

In a survey performed in the US in 2008, the authors found that average precipitation did not affect the proportion of colonies lost in a region (vanEngelsdorp et al., 2008). However, Switanek's team revealed that the higher winter losses also followed a dry season (Switanek et al., 2017). During a dry summer, because of low bee forage, the development of the bee population is insufficient to prepare strong colonies for winter. In Poland a similar mechanism could have occurred but caused by a very high total precipitation in July 2011. The situation was worsened by very low temperatures during December, unfavorable for colonies not strong enough to maintain proper temperature in the winter cluster. The high temperatures in July 2011 probably only contributed to the formation of storms associated with high precipitation and we are not able to suggest their more direct links to losses. Van der Zee et al. (2015) suggest that bad weather, that is high precipitation in July and August, played an important role in the observed honey bee colony winter losses in the Netherlands, because reduced foraging opportunities in this period may have impacted adversely on the production of a healthy winter population, not only by deprivation of the necessary food supply, but also because starvation increased the toxic effects of thiacloprid and acetamiprid. In their opinion these effects may be playing a role in areas with reduced food sources in

summer under less extreme weather conditions also.

The results of the work presented here show that the problem of high winter losses in Poland did not have an incidental character, but concerned almost all the winters between 2006- 2012, and that such climatic factors as a warm autumn or high precipitation during summer, followed by low temperatures during winter, most probably influenced the spatial distribution of those losses. It would be interesting to compare the spatial distribution of colony losses in Poland with the maps of land use and pesticide application in agriculture, although hitherto Polish researchers (Pohorecka et al., 2012; Pohorecka et al., 2017) have not found any relationship between the high winter colony losses and pesticide content in samples collected from colonies.

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